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Factors affecting ewe longevity on sheep farms in three European countries

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Abstract

The ability to identify ewes that can outperform their contemporaries, in terms of how long they remain productive in the flock, will help towards improving flock efficiency and profitability. The main objectives of this study were to: 1) identify the main reasons for mortality or culling within diverse sheep production systems in Ireland, Norway and UK; 2) investigate the influence of early life factors on ewe longevity within each of these systems; and 3) determine whether common approaches or recommendations could be employed to improve ewe longevity. The main reasons for mortality or culling were, in addition to old age, mastitis (Irish and Norwegian sheep) and tooth loss (UK hill sheep). In each country, there were significant differences in age at last lambing due to the year the ewe was born (but in no consistent pattern), and due to her flock of birth ($P<0.05$). From the Norwegian data, there was some indication ewes from younger dams lambed for the last time at a younger age, however, this trend was not seen in the Irish or UK data. Ewes born as singletons, in the Irish data, lambed for the last time at an older age than those that had been born in larger litters, although this was not observed in the other data sets. Age at first lambing and some breed proportions (proportion of Texel and Suffolk particularly) of the animal (both not fitted in the Norwegian or UK analyses) were found to have a highly significant ($P<0.0001$) effect on age at last lambing in the Irish analyses. The results suggest that longevity is influenced by a range of different factors and the early life predictors investigated could

not be used to provide consistent recommendations across countries, production systems and breeds that would influence ewe longevity. One common definition or solution to select ewes for longer productive life in divergent sheep flocks may not be appropriate.

Keywords (3-6 words): longevity, culling, ewe, sheep

1. Introduction

Ewe longevity has long been regarded by sheep breeders across Europe, and internationally, as an economically important trait in a breeding ewe flock, due to the potential to reduce culling rates and female replacement costs. The ability to identify ewes that are able to outperform their contemporaries, in terms of how long they remain productive in the flock, will help towards improving flock efficiency and profitability. Fewer unproductive animals on farm will also reduce greenhouse gases emissions per kilogram of lamb produced, providing an additional environmental benefit (Jones et al., 2013).

Production systems for meat sheep vary considerably across Europe, due to differences in environmental and climatic conditions, breed types, subsidy systems and markets, amongst other factors. Therefore, different pressures are exerted on breeding ewes, and their flock-masters, which can influence mortality rates and culling decisions. As a result, research outputs and information on ewe longevity from one country, breed or system may not be relevant or applicable in others.

Ewe longevity has been investigated across several studies in different countries. However, definitions of longevity vary across studies, countries and systems. Nevertheless, there may be common ways of defining ewe longevity as a trait that would allow comparisons across populations in different systems with differing levels of recording. One of the most common traits relating to ewe longevity that has been investigated in the literature is productive life, determined by the number of years the ewe remains in the flock (Borg et al., 2009). Unlike the data available from research flocks, which may record cull/death dates and reasons, data collected from commercially recorded flocks seldom provides sufficient detail to assess different causes of ewes leaving the flock. However, the age of the ewe at her last recorded lambing event is a longevity trait that could potentially be investigated across research and commercial data sets from different sources, in an attempt to better understand commonalities and assess potential to share knowledge across sheep populations.

Results from studies that have investigated the genetic control of ewe longevity suggest that ewe productive life is lowly heritable, with heritability estimates ranging from 0.03-0.13 (Borg et al., 2009; Brash et al., 1994; Conington et al., 2001; Lambe et al., 2008; Lee et al., 2015; McLaren et al., 2017; Zishiri et al., 2013). In addition to estimating variance components for ewe longevity, Conington et al. (2001) also produced some of the first economic weightings for longevity, relating to different types of farming system in the UK. However, there are few international examples of longevity traits included in national breeding indices, or as stand-alone breeding values, using commercially recorded data available from performance recording schemes (Ireland and New Zealand: Santos et al., 2015; UK Lleyns: McLaren et al., 2017), and breeding values for ewe longevity are not yet widely available in most countries.

Before attempting to move to a genetic solution for increasing ewe longevity across countries, it is important to understand the main causes of ewe mortality or culling (voluntary or involuntary) within systems, and to attempt to identify early life predictors. This information may help us to understand whether the same trait is being compared across populations and whether common solutions to extend ewe longevity are possible or appropriate.

The objectives of this study were to: 1) identify the main reasons for mortality or culling within diverse sheep production systems in Ireland, Norway and UK; 2) investigate the influence of early life factors on ewe longevity within each of these systems; and 3) determine whether common approaches or recommendations could be employed to increase ewe longevity across different European sheep production systems.

2. Materials and methods

2.1. Recording mortality and culling reasons

Currently, the national sheep performance recording systems in both Norway and Ireland provide farmers the opportunity to record reasons for death or culling. This has not been the case in national

UK breeding programmes, but detailed information is available from research flocks, which provide an indication of the common reasons for animals leaving similar commercial-type flocks.

The Norwegian Sheep Recording System (SRS) was established in the 1950's and is voluntary. It is now hosted by Animalia – Norwegian Meat and Poultry Research Centre (Animalia, 2018). The minimum requirements for recording are: animals joining or leaving the flock (dead or alive); lambs born; and an autumn weight on all lambs. Slaughter data on individuals are automatically transferred from the abattoirs. It is also compulsory for members of ram circles to be members of the SRS and, in recent years, an increasing number of traits (i.e. mating information, birth weights, teat size and reasons for a ewe leaving the flock) are now required to be recorded. Approximately 40% of all sheep flocks, and 52% of all ewes, in Norway report to SRS. The most commonly recorded breed is the Norwegian White Sheep (NWS), making up 69% of the ewes in the SRS (Animalia, 2018).

Sheep Ireland, and the Sheep Ireland database, were formed in 2009. Performance data, from just over 700 commercial and pedigree ram breeding flocks throughout Ireland, are currently recorded through the LambPlus performance recording service (https://www.sheep.ie). Growth, lambing and litter size are the main elements of the genetic evaluation and sheep breeders can use the Terminal and Replacement overall indexes to implement breeding improvement (Pabiou et al., 2014). Traits are recorded across a wide range of pure- and cross-bred animals, but Texel, Suffolk, Charollais, Belclare, and Vendeen sired animals provide the bulk of those performance recorded. Ewe longevity is not currently a trait included in the Sheep Ireland genetic indexes but a major focus is now being put on building a large dataset of accurate culling and death reasons from all performance recording flocks.

For the current study, death and cull data for the UK analyses were from performance recorded Scottish Blackface ewes, based on SRUC's hill and upland research flocks, one in the Pentland Hills, near Edinburgh, the other in the Western Highlands, near Crianlarich. These flocks have been performance recorded since 1999 and the data used to develop a multi-trait selection index suitable for hill sheep breeds (Conington et al., 2001). The selection index created has gone on to form the basis of the commercial Hill-2 Index, which is currently available to commercial UK hill sheep breeders through the Signet Sheepbreeder Service (http://www.signetfbc.co.uk/). Although longevity was included as a trait in the selection index developed by Conington et al. (2001), it is not currently included in the Hill-2 index. However, details were available for every death or cull across both research flocks and, as these flocks are recorded as part of the Signet Sheepbreeder Service, these were deemed to be representative of the data that would be submitted from similar UK hill-type flocks.

Data from these three sources were assessed to identify the main reasons for ewes, over one year of age, leaving the flock. Details of the full range of options provided for recording death or cull reasons are given in the supplementary material. The data available from each country included: 113,319 records from Norwegian White Sheep ewes, reared on SRS ram circle flocks, recorded between 2011 and 2016; 23,880 records from pure- and cross-bred ewes reared on commercial Irish flocks, recorded between 2010 and 2016; and 3,224 records from Scottish Blackface hill ewes recorded on SRUC research flocks between 2003 and 2016.

2.2. Early life factors affecting ewe longevity

The definition of ewe longevity used in these analyses was the age (in years) at the last recorded lambing event. The data available from each country included: Norway, n=55,703 records, from Norwegian White Sheep ewes born between 2001 and 2012; Ireland, n =14,213 records, from ewes born between 2004 and 2011; and UK, n=3,173 records, from Scottish Blackface ewes born between 2002 and 2011.

2.2.1. Statistical analyses

A number of different fixed effects and covariates were tested using generalized linear models in Genstat (VSN International, 2013) or SAS® software (SAS Institute, 2013). Stepwise regression was then used to identify a suitable final model for the analyses for each country's data set.

The common effects used across all countries included ewe birth year (Norway 12 levels, 2001-2012; Ireland 8 levels, 2004-2011; UK 10 levels, 2002-2011), flock of birth (Norway 415 flocks; Ireland 368 flocks; UK 2 flocks), the age of the ewe's dam (Norway 6 levels, 1 to $\geq$6; Ireland 7 levels, 1 to $\geq$7; UK 5 levels, 2 to $\geq$6), litter size of the ewe when she was born, her birth weight and her live weights recorded between 6-8 weeks old and between 14-20 weeks old (as well as squared live weights in the Norwegian and UK analyses, to test if live weight had a non-linear quadratic effect on age at last lambing). All weights were fitted as covariates. In the UK and Irish data, live weights recorded between 6-8 weeks old were corrected to 56 and 40 days old respectively, as these are the recommended ages for weighing lambs within these breeding programmes. Weights were corrected to a fixed age by linear regression of live weight on age, using the predicted mean weight at the specified age plus the residual value for each individual lamb. Similarly, for those recorded between 14-20 weeks old, the live weights were corrected to 111 and 100 days old respectively. The Norwegian live weight data was live weight gain from birth to the respective weighing event, corrected to 42 and 140 days old. An interaction term between ewe birth year and flock were fitted in the Norwegian and UK models, but was dropped from the Irish analyses due to non-significance. The Irish model also included age of the ewe at her first lambing event (>8 and <18 months of age, or ⩾18 and <28 months of age), and the breed composition for each animal for the main recorded breeds (Texel, Suffolk, Charollais, Belclare or Vendeen), since the data contained both pure- and cross-bred animals. In the Norwegian and UK data sets, ewe age at first lambing was not fitted in the models, for the reasons explained below.

The final model used across the datasets in each country was therefore:

Age at last lambing = Ewe birth year + Flock of birth + Dam age + Ewe birth weight + Birth litter size + Live weight (6-8 weeks old) + [Live weight (6-8 weeks old)]^2* + Live weight (14-20 weeks old) + [Live weight (14-20 weeks old)]^2* + (Ewe birth year x Flock of birth)* (+ *age at first lambing* + *breed proportion Texel* + *breed proportion Suffolk* + *breed proportion Belclare* + *breed proportion Charollais* + *breed proportion Vendeen*)**

*Fitted in the UK and Norwegian analyses only

** Fitted in the Irish analysis only

An overall summary of the data available for the effects fitted in the models, are shown in Table 1**.** When an effect was identified as a significant source of variation (and included less than 10 factors), least-squares means (LSMs) and standard errors of the means (SEMs) were estimated. Differences between the means were then tested using a t-test to identify significant differences between factors, within country.

Other important points to note are that in the Norwegian and Irish analyses, any ewes that missed a lambing event during their lifetime (i.e. had a lambing interval over 600 days at any point in their life) were removed completely from the analyses. Also, all animals in the Norwegian dataset had to have a lambing event at 1 year old to be included in the analyses, whereas the Irish data included ewes that lambed for the first time as a 1 or 2 year old. The UK data did not include any ewes that lambed as a 1 year old (which is uncommon in UK hill flocks), and did include ewes that missed one lambing year (either through barrenness or lamb loss).

3. Results

3.1 Reasons for mortality or culling

The main reasons submitted for ewes leaving the flock (those representing over 5% of records in each data set), in each country, are given in Table 2. The proportion of ewes culled due to old age ranged from 12.4% to 23.5%. A common problem identified in both Norway and Ireland was mastitis (19.9% and 13.5% of ewes culled, respectively), whereas in the UK data set, the highest proportion of animals were culled due to problems associated with their teeth (38.9%). In addition to mastitis, a relatively high proportion of animals in the Norwegian data set were culled for udder/teat damage or poor udder conformation (16.9%), with a smaller proportion culled due to udder-related problems in the Irish data (5.7%). Although not shown in Table 2, mastitis only accounted for 3.4% of the reasons provided in the UK data. Poor body condition contributed to the most common culling reasons in the Irish (5.7%) and UK (6.8%) data sets, whilst reproductive issues accounted for 6.3% and 5.4% of culls in the Norwegian and UK data sets, respectively. Ewes that were known to have died, but no reason was attributed, made up 19.9% and 3.8% of the reasons in Ireland and UK data sets, respectively. Additionally, ewes identified as being sold straight to an abattoir for slaughter made up 15.9% of the Irish data. Ewes identified as being missing, and therefore presumed dead, accounted for 6.8% of the UK data. The remaining reasons, not listed in Table 2 but given in the supplementary material, when combined, made up 44.5% (n=19 reasons), 12.0% (n=7 reasons) and 18.6% (n=9 reasons) of the Norwegian, Irish and UK data, respectively. These remaining reasons included lambing associated problems (e.g. prolapses, abortions, poor mothering ability and lambing difficulties), physical reasons (e.g. bad feet or legs), poor genetics (estimated breeding values and/or overall index values) and health related issues (other than mastitis). Norway also had a number of records associated with overall management reasons (e.g. food shortages) and predators (of which there were 8 different sub-reasons, e.g. taken by a wolverine, wolf or lynx).

3.2 Early life factors affecting age at last lambing

The summary statistics for age at last lambing in the data sets from Norway, Ireland and the UK are given in Table 3.

The frequency of the data available from each country, for age at last lambing, is shown in Fig 1. The distributions vary across countries. In Norway, last lambing events were fairly evenly spread across ages – ranging from 12-20% from 1 to 6 years old. Just over 20% of the records available were for ewes who's first lambing was also their last lambing (at 1 years old), and 18.7% of the records were from ewes that were 6 years old. In the Irish data, the distribution appeared to be more normal in shape across ages from 1-7 years old, with 6.4% and 12.4% of the age at last lambing records for ewes aged 1 or 2 years old and a peak of around 21% at 4 and 5 years old. However, it should be noted that the average age at first lambing was 1.88, therefore not all ewes had the opportunity to lamb as a 1 year old. In the UK data, just over 20% of the age at last lambing data records were from 2 and 3 year old ewes (combined). The most common age for ewes to leave the flock was at 5 years old (42.6% of the UK data records).

Fig. 1 here

Of the early life predictors tested in the models, only the birth year of the ewe and her flock of birth significantly (P<0.05) affected age at last lambing across all three analyses (Table 4). The age of the ewe's dam and the interaction between birth year of the ewe and the flock of birth had significant (P<0.05) effects on age at last lambing in both the Norwegian and UK analyses. Other significant effects (P<0.05) included birth litter size of the ewe in the Norwegian and Irish analyses and the weight of the ewe recorded between 6-8 weeks and at 14-20 weeks (squared) of age in the Irish and UK analyses, respectively. Age at first lambing and the proportion of Texel, Suffolk and Belclare breed in the animal (not fitted in the Norwegian or UK analyses) were found to have a highly significant (P<0.001) effect on age at last lambing in the Irish analyses. The amount of variance accounted for by the combined terms in the models (R^2) and the residual means standard error (RMSE) values are also given in Table 4.

In order to investigate the direction and magnitude of the significant effects on age at last lambing, for informative early life predictors, least-squares means (LSMs) and standard errors of the means (SEMs) were estimated. For the age of the ewe's dam, no clear relationships were observed (Fig. 2). In the Norwegian data, ewes with a dam aged 1 or 2 years old had a significantly lower age at last lambing compared with those with a dam aged 3 years or older. However, in the UK data, ewes with a 3 year old dam had a significantly lower age at last lambing ($P<0.05$) when compared with those with a 2 or 4 year old dam, whilst other dam age groups did not differ significantly. There were no significant differences between dam ages observed in the Irish results.

The effect of birth litter size (Fig. 2) was most evident in the Irish data, with significant ($P<0.05$) LSM differences observed between those born as singles, twins and triplets. Those born as a single had their last lamb, on average, 6 months later than those reared as triplets (5.5 years for singles and 5.0 years for triplets). The average age at last lambing for those reared as quadruplets was not significantly ($P>0.05$) different from those reared as twins or triplets. In the Norwegian data, there was a significant increase in the average age at last lambing ($P<0.05$) observed in ewes that were born as twins, compared with those born as triplets, but neither of these litter sizes were significantly ($P>0.05$) different to singles or quadruplets. There was no significant different between ewes born into different litter sizes ($P>0.05$) in the UK data. There was a tendency for triplet-born ewes to have their last lamb at an earlier age, but low numbers in this category in the data set led to a high standard error associated with the mean.

Age at first lambing was only fitted in the Irish analyses. The LSM results from these analyses found that the mean age at last lambing was significantly lower ($P<0.05$) for ewes that had lambed for the first time as a 1 year old compared with those that lambed for the first time at 2 years old. The mean age at last lambing was 4.6 $\pm$0.19 and 5.3 $\pm$0.18 years, respectively.

Fig. 2 Here

4. Discussion

4.1. Common reasons for ewe mortality/culling

Breeding schemes across all three countries and sheep systems studied have seen improvements in traits associated with growth, reproductive performance and carcass characteristics (Eikje et al., 2008; Lambe et al., 2014; Santos et al., 2015). Improving ewe longevity remains another important goal, due to economic, environmental and welfare related benefits, but progress has proven to be difficult due to the trait being lowly heritable, expressed later in life, and influenced by a range of different factors (Lee et al., 2015). In an attempt to gather more detailed information as to why ewes are leaving the flock at certain ages, both performance recording schemes in Norway and Ireland have, in recent years, provided farmers the opportunity to submit animal fate information. Disposal reasons have also recently been introduced in the UK national recording schemes, but it will take a few years for enough data to be collected before it can be analysed in detail. In the meantime, data available from research flocks provides an indication as to why and when ewes are leaving extensive-type hill farms similar to those being recorded in the national breeding scheme.

The most common reasons for mortality/culling, submitted by flock-masters, varied across all three countries. In Norway, the most common reason was mastitis, closely followed by other udder associated problems, which included issues such as poor conformation or damage to the udder or teats. Mastitis and udder problems also featured strongly for ewes in the Irish data, but much less so for ewes in the UK data from the hill flocks (<5%). The high proportion of Norwegian White Sheep in Norway culled for mastitis (plus other udder problems) may be influenced by the fact they are a prolific breed (Jakobsen et al., 2017). Large litters, plus the emphasis on lamb growth and carcass characteristics, may increase suckling frequency and increase the potential for damage to the udder. Indeed, Larsgard and Vaabenoe (1993) and Waage and Vatn (2008) observed, when previously assessing mastitis in Norwegian sheep breeds, that the incidence of mastitis increased as litter sizes increased. Previous research from Ireland also found that the incidence of mastitis increased with ewe age (O'Brien et al., 2017). This, coupled with the large proportion of terminal sire bloodlines represented in the Irish data (Texel, Suffolk and Charollais), which are also often associated with high lamb growth rates, may explain why mastitis features highly as an end reason in the Irish data. In addition to the premature culling of the ewe herself, the disease can also prove expensive in terms of treatment costs and poor lamb growth rates, therefore having a considerable impact on affected flocks (Bergonier and Berthelot, 2003; Conington et al., 2008; Gelasakis et al., 2015; McLaren et al., 2018).

Although Conington et al. (2008) reported mastitis to be the single biggest reason for premature culling in UK Texel sheep, the data available from the UK in the current study was based on records from Scottish Blackface hill ewes, in which there was a very low incidence of mastitis. This observation would be in line with findings from an earlier Norwegian study comparing incidence in different breeds and pasture types, with ewes on lowland pasture having a higher incidence when compared with those in hill or mountain environments (Larsgard and Vaabenoe, 1993). If ewes spend the majority of their time in an extensive hill or mountain environment lower incidence of mastitis may be observed, due to the reduced opportunity for causative bacteria to spread and infect other animals. Ewes that are housed around lambing time may be at a higher risk of infection if there are high stocking densities and poorer hygiene, bedding quality and ventilation levels, all of which provide favourable conditions for bacteria to develop and spread more easily (Gelasakis et al., 2015). There are also lower litter sizes associated with ewes in extensive hill farm systems and Scottish Blackface lambs are often associated with slower growth rates, when compared with terminal sire lambs (Lambe et al., 2007). It could be hypothesised that cull data from terminal sire breeds in the UK may be more similar to the Norwegian and Irish data presented here, although the data were not available to test this in the current study.

The data available from the UK hill flocks indicates that the most common reason for mortality/culling in hill ewes was problems identified with their teeth, predominantly tooth loss, also known colloquially as “broken mouth”. Ewes were culled if they had lost at least one of their four centre permanent incisors, usually identified in late autumn when farmers typically sort through their flocks to remove ewes not fit for further breeding, or which are considered unlikely to survive through the winter months. MacGregor (2011) also highlights a number of studies that show tooth loss can lead to reductions in the live weight of the ewe (Dove and Milne, 1991; Williams 1993) and is associated with potential reductions in feed intake. Annett et al. (2011) observed that the survival probability of hill ewes fell gradually as the number of teeth missing increased. There have been a number of different reasons linked to the development of tooth loss, including the effects of farm of origin, pasture type, breed, mineral nutrition and supplementary feeding to name just a few (MacGregor, 2011). Less than 5% of the ewes recorded in Ireland were recorded as having been culled due to their teeth whereas the option to identify ewes culled specifically for tooth loss was not available to farmers in Norway. It is therefore possible that some ewes with missing teeth may have been identified in the Norwegian data set as being culled for age, body condition, or another reason.

Ewes culled because of their age also featured relatively highly across all three countries. In the UK, it is common practise for hill ewes to leave the flock at 5 years old, having had 4 lamb crops. These ewes would then be sold either for slaughter or onto lowland flocks for further breeding. However, depending on the number of younger replacement ewes available each year, hill farmers may decide to keep some ewes beyond this age, to maintain their overall flock numbers, providing their body condition is good and they have retained all of their teeth. As the UK data in this study came from research flocks where a strict culling policy was adhered to, animals were only recorded as culled for age if there were no other reasons for culling them. This might not necessarily be the case in the Norwegian or Irish data as, mentioned earlier, some of these animals recorded as being culled for age could have been culled for other reasons such as tooth loss.

4.2 Early-life predictors of age at last lambing

In addition to identifying the main reasons for mortality/culling in flocks across Norway, Ireland and the UK, this study also investigated potential early-life predictors of ewe longevity across all three countries. The longevity trait selected was age at last lambing, as this was easily defined in the data collected from different performance recording schemes and could be compared across all countries. The data available for age at last lambing, from each country, revealed that on average, ewes in Norway left the flock at 3.38 years old, whereas those in Ireland and the UK left at 4.22 and 4.35 years old, respectively, although no statistical test could be performed to formally assess differences between countries. It should also be noted that all of the Norwegian ewes lambed for the first time at 1 year old, whereas ewes in the UK data did not have their first lamb until they were a year older. The Irish data contained ewes that lambed for the first time as both 1 and 2 year olds, although an average age at first lambing of 1.88 would indicate a higher proportion of ewes were lambing for the first time as a 2 year old.

The age at last lambing records differed across all three countries, likely influenced by the main mortality/culling reasons highlighted above and the rules imposed for retaining data in the different analyses. In Norway and Ireland, approximately the same percentage of ewe records came from each age group (1-6 years old). This would match with the fact that a high percentage of ewes are culled for mastitis and other udder associated problems, which can occur at any point throughout the ewe's lifetime. In contrast, the percentage of age at last lambing records available for ewes culled in the UK hill flocks increased steadily up to 5 years old before tailing off in later age groups. This pattern reflecting the fact that the main culling reasons identified were tooth loss or age, both of which are traits associated with later life. Results observed by Mekkawy et al. (2009), found that younger crossbred Mule ewes were most commonly culled for udder problems, such as mastitis, whereas the number of ewes culled for teeth associated issues increased substantially after 4 years old.

In terms of possible early-life factors that may predict how long the ewe will remain in the flock, the results were not consistent, with very few factors being significant across all three countries. Age at last lambing was significantly affected by birth year of the ewe across all analyses, for the years that were studied here, but predicted means for these years could not be used to predict future ewe longevity. Other significant effects included the ewe's dam's age. This was most evident in the Norwegian analyses, where ewes born to younger dams (i.e. 1 and 2 year olds) left the flock earlier than ewes born to older dams. Recent results from New Zealand have found that the survival rates of ewes born (as a twin) to 1 year old mothers were shorter when compared with those born to older ewes, although it should be noted that a relatively small number of animals were used in this study (Pettigrew et al., 2019). The relationship in the UK analyses, although significant was less clear. Interestingly, age at first lambing (only fitted in the Irish analyses) proved to be a significant effect and suggested ewes lambing for the first time as a 1 year old left the flock earlier than those who lambed for the first time at 2 years old. Positive genetic and phenotypic correlations between age at first lambing and age at last lambing have previously been observed by McLaren et al. (2017) in Lleyn and Dorset sheep in the UK and therefore in agreement with the Irish results in this study. However, in contrast, Kenyon et al. (2011) found breeding Romney ewes at 1 year old did not significantly reduce their longevity. This variation in results suggests there could be breed and environment differences, and further investigation may prove useful.

4.2 Limitations and recommendations

Over the course of this study, several limitations were identified, particularly in terms of accurately assessing differences between countries. Having identified the main reasons across each country (mastitis, tooth loss and old age) there remains a wide range of additional reasons provided by each recording scheme that farmers can allocate to each ewe. The question therefore arises – in how much detail should cull reasons be recorded? Is it more valuable to capture detailed information on why the ewes are leaving the flock, or should the number of recorded culling reasons be minimised to identify the main reason types and simplify recording? The reasons identified as responsible for over 5% of culls/deaths in each country did not include any lambing-related issues or physical/structural reasons, such as those associated with the legs or feet, which could potentially be under genetic control. Providing culling reasons such as old age or slaughter on a list of options, may mean that breeders record these reasons as a default, rather than the root causes, which may include poor body condition, tooth loss, lambing or reproductive issues, for example. Clear instruction should therefore perhaps be provided to breeders to ensure that culling or death reasons that could have a genetic basis are identified as the primary cause for ewe removal from the flock. Involuntary reasons, such as ewes lost due to accident/injury, predation, or sold for management reasons such as food shortages (the latter two particularly relevant to Norway), were also all below the 5% threshold. These involuntary culls or deaths are useful to know for management or compensatory reasons, but could be combined, and records potentially removed, for consideration of longevity within genetic analyses.

With mastitis and tooth loss being the main drivers of ewes leaving the flock in these data sets, genetic analyses of these direct traits could be a useful option to explore in order to try to reduce the impact these traits have in terms of longevity. These traits would be more easily defined and may be affected less by management policies across different farms, reducing residual variation compared with the more general trait of age at last lambing. This could potentially increase the heritability of the trait under selection, leading to faster genetic gain. However, to include reduced mastitis or tooth loss in future breeding goals, accurate recording of these traits by the breeders would be required. The two traits are very different in terms of their effect, mastitis affecting ewes of all ages while tooth loss predominantly affected older ewes. They are also very different due to the nature of the different breeds and systems studied in the present analyses - mastitis affecting predominantly terminal sire type breeds (i.e. high growth rates, high litter sizes) with lower incidence in a more hill type breed; whilst tooth loss tends to be more prevalent in ewes grazing poorer quality hill swards.

Due to the different management and breed structures of the data available from each country, only observational comparisons between countries could be made. Although the final models used to assess age at last lambing were as similar as possible, the different analyses could not be compared using any statistical analyses. The main differences across the three countries, which could not be ignored in the models used, were the breeds involved (pure breeds in Norway and UK compared to a mix of pure and crossbred animals in Ireland) and the age of the ewes at their first lambing (one year old in Norway, two years old in UK and a combination of both in Ireland). Nonetheless, these analyses help towards improving our knowledge and understanding of factors influencing ewe longevity across each country. The results from this study, both in terms of the main reasons identified across each country for mortality/culling and the analyses of age at last lambing to assess ewe longevity, suggest further work would be beneficial before attempting to combine data across countries or systems, or infer longevity implications in one country based on results from another.

5. Conclusion

This study has helped to further our understanding of the main causes of ewe mortality or culling (voluntary or involuntary) across 3 different European sheep production systems. Differences were observed in the retention rate of breeding ewes in the flocks across ages, as well as in the main reasons for ewes leaving the flock, which suggest that longevity is influenced by different factors across countries and systems. The early life predictors investigated could not be used to provide consistent recommendations across countries and production systems that would influence ewe longevity. Therefore, one common definition or solution to select ewes for longer productive life in divergent sheep flocks may not be appropriate.

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Table 1. Summary statistics for the fixed effects fitted in the linear models

	Norway				Ireland				UK			
Effects fitted	Av.	S.D.	Min	Max	Av.	S.D.	Min	Max	Av.	S.D.	Min	Max
Ewe birth weight (kg)	4.93	0.94	1.5	9.5	4.55	1.06	2	10	3.77	0.66	1.6	6.5
Ewe weight – approx. 6-8 weeks old (kg)*	14.56	2.72	5	30	19.30	3.81	12	32	18.15	1.04	14.2	22.17
Ewe weight – approx. 14-20 weeks old (kg)**	39.95	4.64	30	50	35.62	6.91	20	55	27.41	1.05	24.1	31.98
Ewe age at first lambing (years)	-	-	-	-	1.88	0.33	1	2	-	-	-	-
Dam of ewe age (years)	2.60	1.19	1	6	2.76	1.54	1	7	3.51	1.15	2	7
Birth litter size of ewe	2.41	0.75	1	4	1.87	0.68	1	4	1.59	0.53	1	3
Breed proportion of Texel (%)	-	-	-	-	45.91	48.69	0	100	-	-	-	-
Breed proportion of Suffolk (%)	-	-	-	-	16.89	35.16	0	100	-	-	-	-
Breed proportion of Belclare (%)	-	-	-	-	18.48	35.16	0	100	-	-	-	-
Breed proportion of Charollais (%)	-	-	-	-	5.20	21.59	0	100	-	-	-	-
Breed proportion of Vendeen (%)	-	-	-	-	4.70	20.21	0	100	-	-	-	-

*Ewe live weight: live weight corrected to 56 and 40 days old for UK and Irish data, respectively. Live weight gain from birth corrected to 42 days old for Norwegian data
**Ewe live weight: live weight corrected to 111 and 100 days old for UK and Irish data, respectively. Live weight gain from birth corrected to 140 days old for Norwegian data

Table 2. Most numerous cull and death reasons provided by commercial/research farms in Norway, Ireland and the UK (as a percentage of total ewe deaths or culls recorded in each country)

Norway	Ireland	UK
Mastitis (19.9%)	Age (20.9%)	Teeth (38.9%)
Udder problems (16.9%)	Died (reason unknown) (19.9%)	Age (23.5%)
Age (12.4%)	Slaughtered (15.9%)	Body condition (6.8%)
Non-breeder (6.3%)	Mastitis (13.5%)	Missing – presumed dead (6.8%)
	Unknown reason (6.4%)	Reproductive disorder (5.4%)
	Body condition (5.7%)	
	Udder problems (5.7%)	

Table 3. Summary statistics for age at last lambing data available from Norway, Ireland and the UK

	Norway				Ireland				UK			
Trait	Av.	S.D.	Min	Max	Av.	S.D.	Min	Max	Av.	S.D.	Min	Max
Ewe age at last recorded lambing event (years)	3.38	1.79	1	6	4.22	1.68	1	7	4.35	1.12	2	7

Table 4. Details of the effects fitted in each model, and their significance, across each country.

Effects fitted in the models	Norway	Ireland	UK
Ewe birth year	✓***	✓***	✓***
Flock of birth	✓***	✓***	✓*
Dam age	✓***	✓ns	✓*
Ewe birth weight	✓ns	✓***	✓ns
Birth litter size of ewe	✓**	✓***	✓ns
Ewe weight – approx. 6-8 weeks old	✓ns	✓**	✓ns
Ewe weight – approx. 14-20 weeks old	✓ns	✓ns	✓ns
Ewe weight – approx. 6-8 weeks old (squared)	✓ns		✓ns
Ewe weight – approx. 14-20 weeks old (squared)	✓ns		✓*
Ewe age at first lambing		✓***	
Breed proportion of Texel (%)		✓***	
Breed proportion of Suffolk (%)		✓***	
Breed proportion of Belclare (%)		✓***	
Breed proportion of Charollais (%)		✓ns	
Breed proportion of Vendeen (%)		✓*	
Ewe birth year x Flock of birth	✓***		✓***
Variance accounted for by the models (R^2)	10.8%	31.0%	3.5%

Residual means standard error (RMSE)	1.74	1.60	1.14

✓Fitted in model; $^{***}P<0.001$; $^{**}P<0.01$; $^{*}P<0.05$; ^{ns}Not Significant

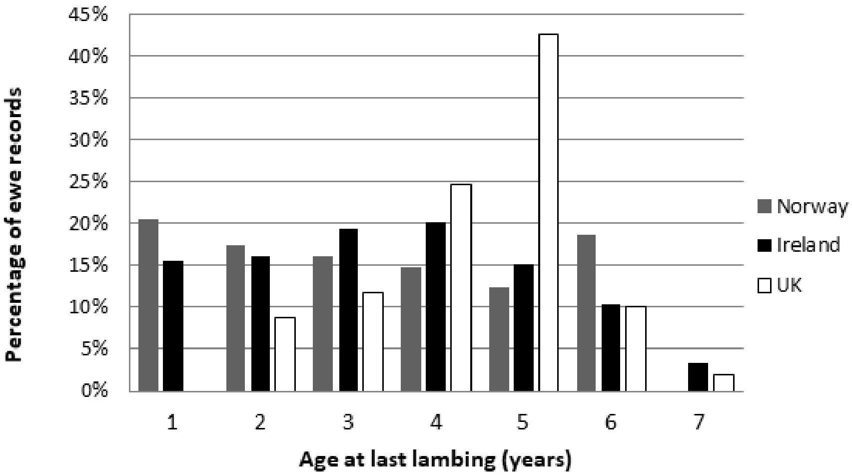

Fig 1. Frequency of age at last lambing across all three counties

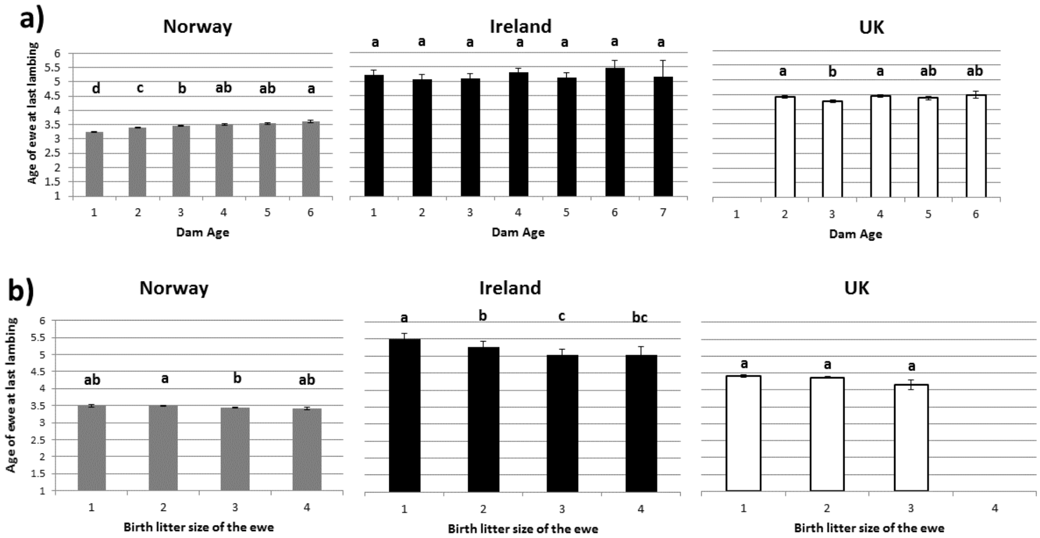

Fig 2. Predicted least squared means for the effects of a) the age of the ewe's dam and b) birth litter size of the ewe across all countries. (Means sharing the same superscript, within country, are not significantly different from each other (P>0.05)).